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Procedure for Near-Simultaneous Testing

by Donald J. Little

ARL-TN-266 December 2006

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14. ABSTRACT

Experiments were conducted to explore the effects of multiple impacts of fragment-simulating projectiles at very close times and impact spacing. This required developing methods to accomplish these rather complex experiments in a reliable and predictable manner.

15. SUBJECT TERMS

near-simultaneous impact, fragments projectile, FSP, ceramic, high-speed photography, 0.22-cal. FSP, 0.3-cal. FSP, 0.5-cal. FSP

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1. Introduction

While ceramic armors have been tested with fragment-simulating projectiles (FSPs) (figures 1 and 2) for decades, no work had been done to study the result of multiple impacts at very close time intervals and spacing, as would occur in an actual fragmenting munition attack. A new multiple gun system was needed in order to launch multiple FSPs into a single ceramic tile with controlled impact times and distances. This system used two guns that were mounted side by side and as close together as possible. One barrel was mounted rigid and perpendicular to the target, and the other barrel was adjustable in azimuth and elevation to allow changing the impact spacing. The targets were mounted in a rigid test stand 6.2 m from the muzzle of each gun. Two flash x-ray channels were used in front of the target for velocity and flight characteristics assessment, and two channels were used behind the target to capture residual debris velocities. Two make-screen circuits were used between the gun and target surface to gather timing measurements. Figure 3 shows an overall view of the range layout used in these experiments. This technical note outlines the methods, equipment, and procedures developed to accomplish these initial near-simultaneous impact experiments.

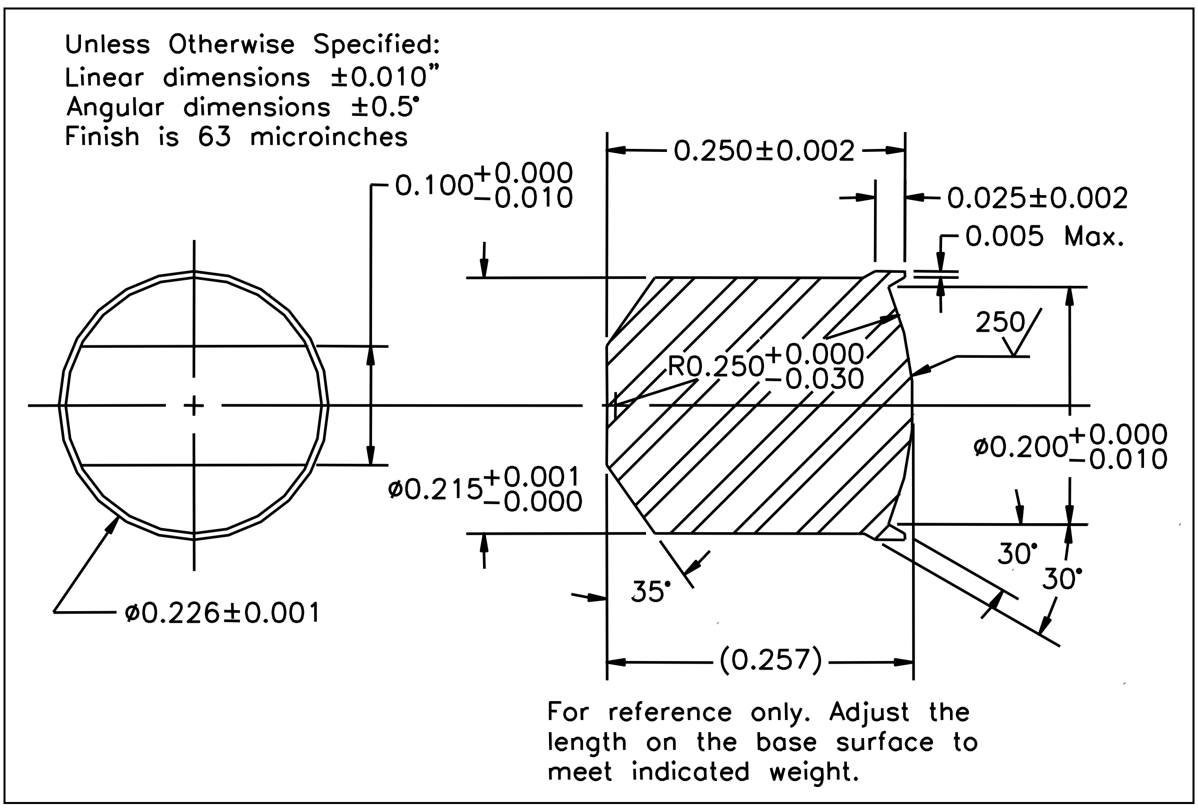


Figure 1. Fragment-simulating 0.22-cal. (types 1 and 2).

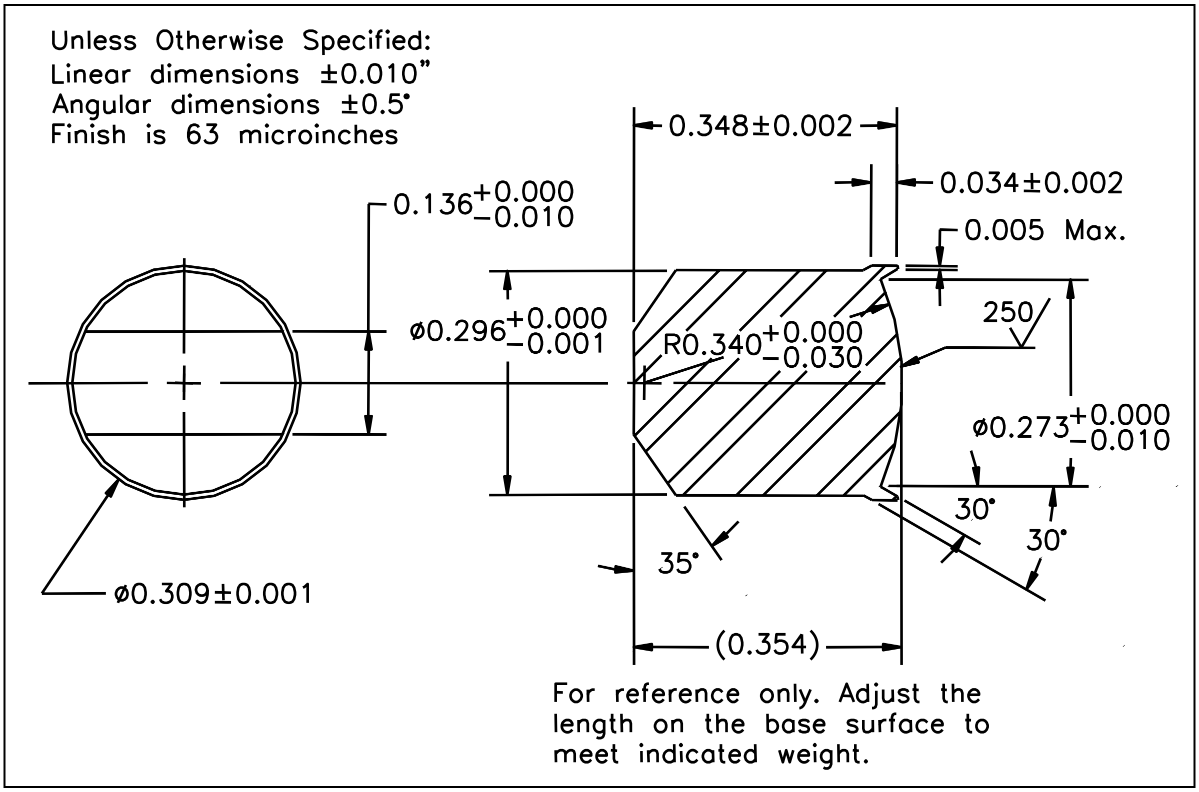


Figure 2. Fragment-simulating 0.3-cal.

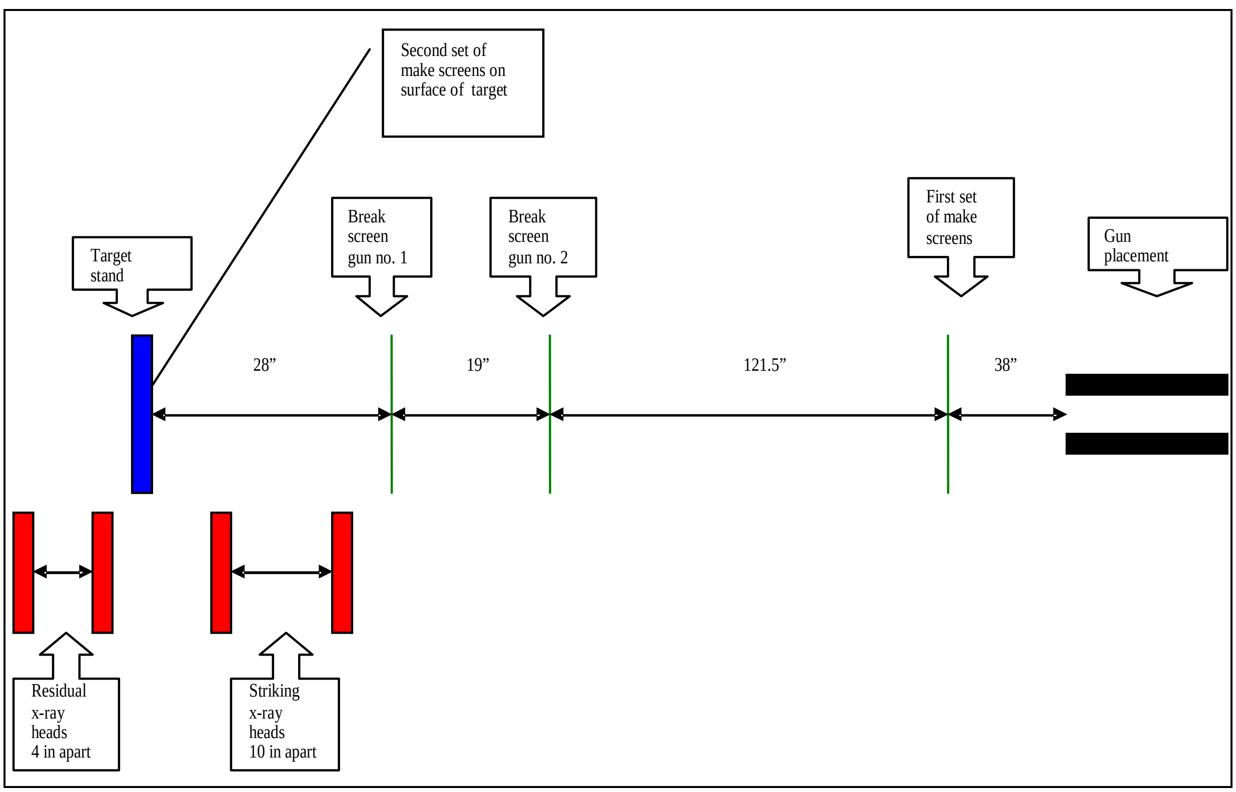


Figure 3. Range layout for near-simultaneous experiments.

2. Barrel Mounting

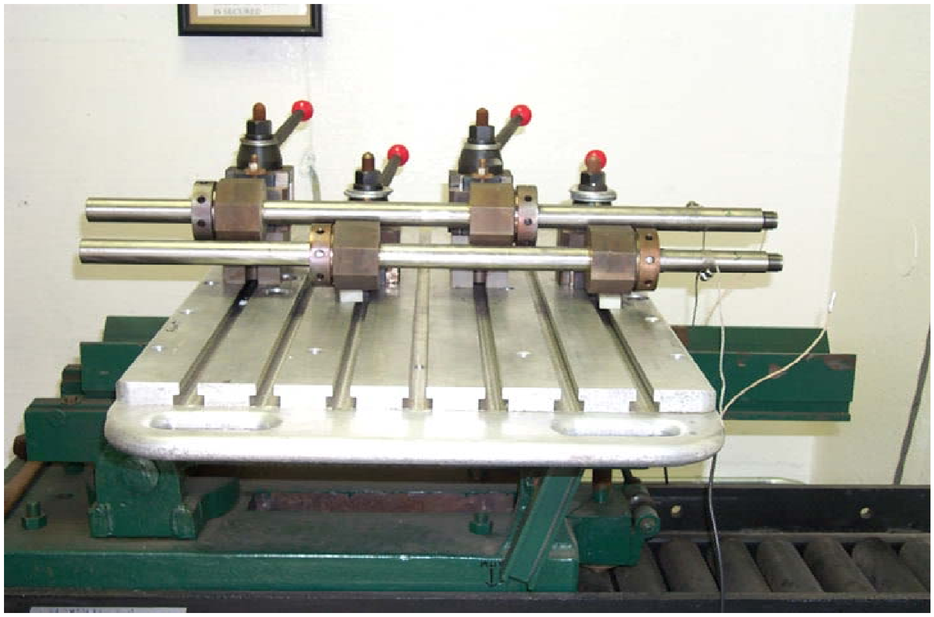
A double gun mount (figure 4) was required to get both projectiles on target in close proximity to one another. A slotted aluminum table that accepts “T” base anchor nuts was used to hold the barrels in place. The table had been drilled to mount directly to a Frankford gun mount, and standard machine tool holders had been modified to hold collets that fit around the gun barrels. The barrels were placed as close together as possible while being parallel to the shot line. For these particular barrels (R-1 and R-2), 2.375-in bore center to bore center was the minimum distance. Spacer plates were machined to hold one of the barrels on a higher plane to prevent images on the x-ray film from overlapping (figure 4b).

3. Target Fixturing

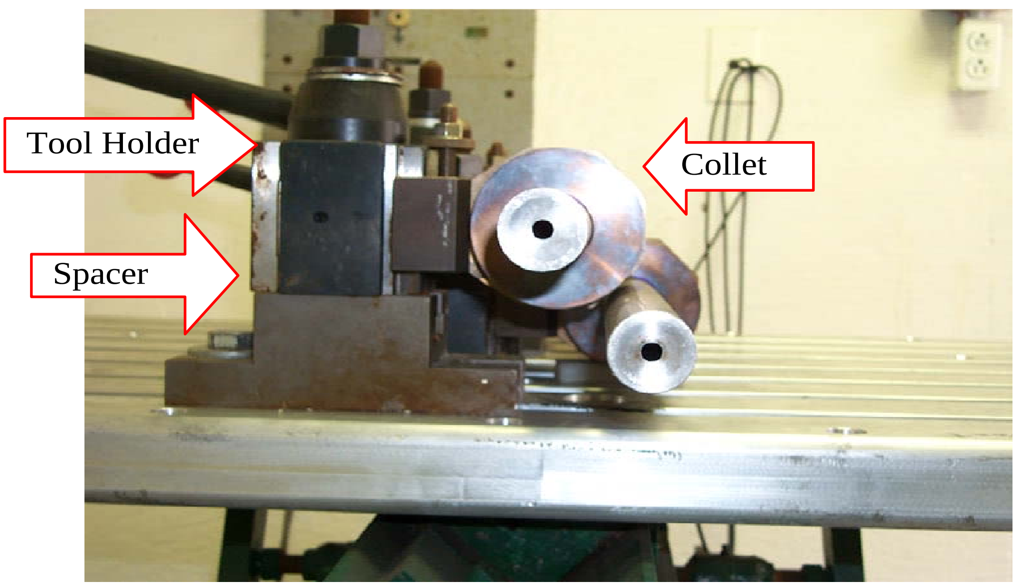
The targets were 152 × 152 mm (6 × 6 in) on the outside and roughly 12.7 mm (0.50 in) thick. A sturdy 25.4-mm (1 in)-thick steel stand (figure 5) was made to hold targets in place. The stand had a removable front plate with through bolts that sandwiched the target firmly in place. High-speed video was used to analyze target impacts and front plate behavior, and a rigid setup was required to accomplish this data collection.

4. Electric Initiation

Initiation of two guns at precisely designated times required the use of an electric primer (the Etronx Large Rifle Primer made by Remington Arms). Early in the program, experiments with percussion primers showed the variation in time was too great to accomplish the tests successfully. Two custom breeches were designed and built to initiate firing the electric primers. Figure 6 shows a breakdown of the pieces that make up the electric breech. The pin body and the threaded pin insert deliver the firing voltage to the center conductor plate of the Etronx primer. Early tests demonstrated that the pin had to be firmly in contact with the primer. Early experiments with a design that used a light duty spring to push the pin forward to make contact with the primer were less than successful. When the primer was initiated, the center conductor of the primer blew backwards toward the pin and destroyed the spring and pin assembly. The internal pressure for electric primers appears to be significantly higher than that of the percussion primers. This problem was solved by making a pin insert that threaded into the pin body,



(a)



(b)

Figure 4. Double gun mount—(a) side view and (b) view looking down bore.

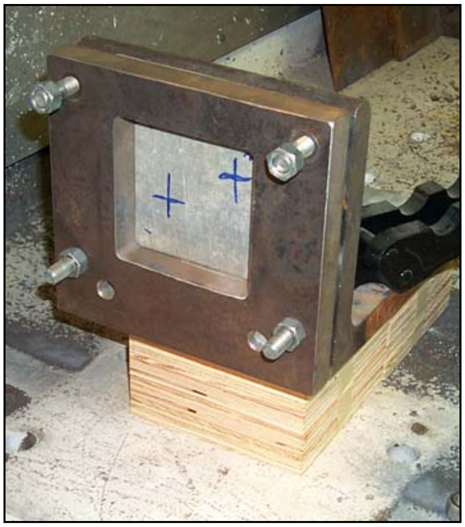


Figure 5. Target stand.

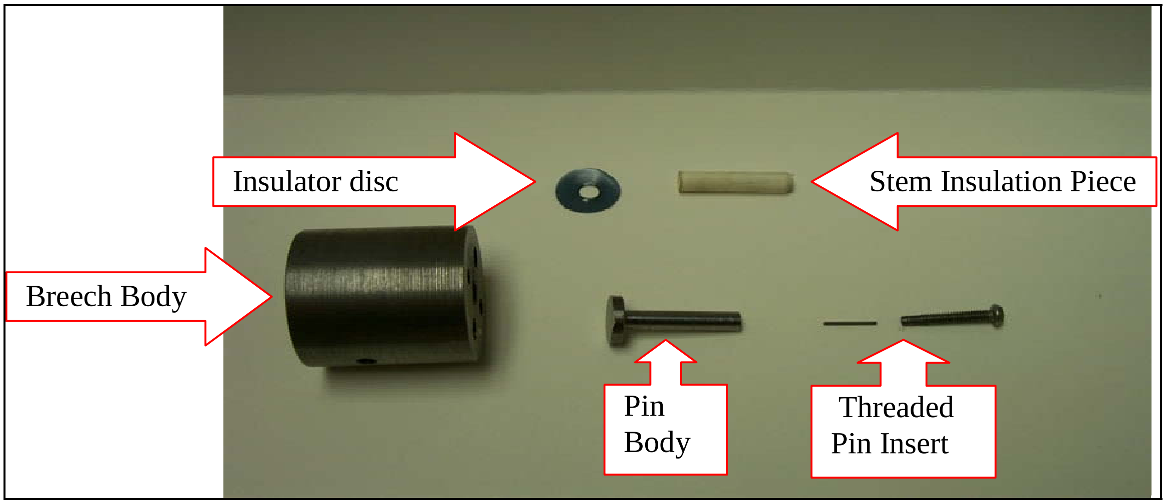


Figure 6. Small-caliber electric breech parts.

thereby providing a firm support for the primer. For this system to function properly, the pin assembly must be electrically isolated from the breech body to insure a single path for current to flow directly to the center conductor of the primer. This was accomplished by applying insulation materials to all surfaces of the pin body. Shrink wrap was applied to the stem, a 0.02-in plastic insulator disc was applied to the back surface of the pin body, and a replaceable tape disc was applied to the front surface of the pin body (figure 7). The breech assemblies needed to be disassembled, cleaned, and checked for damage on all the insulation pieces after each test. The tape on the front surface must be replaced after each test, although the disc and shrink wrap will last for many tests. After reassembly, check with an ohmmeter for continuity to verify that all components were correctly isolated. This only takes about 1 min per breech but it prevents a short circuit in current flow to the primer, which can cause a misfire and loss of test data.

Figure 7. Tape-insulated surface of pin body.

5. Gun Alignment

Gun sighting and alignment were performed with a laser sight fitted to each barrel (figure 8). A commercial handgun laser sight was fitted to a body that threaded on the breech end of each Mann barrel. After an initial test shot, the laser was adjusted to the point of impact for each barrel.

Figure 8. Laser sights.

6. FSP Seating

When seating the FSPs in the barrel, the FSPs needed to be engaged into the rifled portion of each barrel the same distance: ~1.6 mm (0.062 in). Variation in the seating depth causes the velocity to vary, and the velocities had to be kept as predictable as possible in order to achieve the required time of impact. To accomplish this, an insertion tool was built that had a pin with a shoulder on it (figure 9). The body of the tool was drilled and tapped to accept a threaded pin. Once the appropriate length was set, a locking collar was tightened to hold it in place. The FSP was inserted in the barrel with the tool and tapped forward until the shoulder of the tool touched the rear of the barrel.

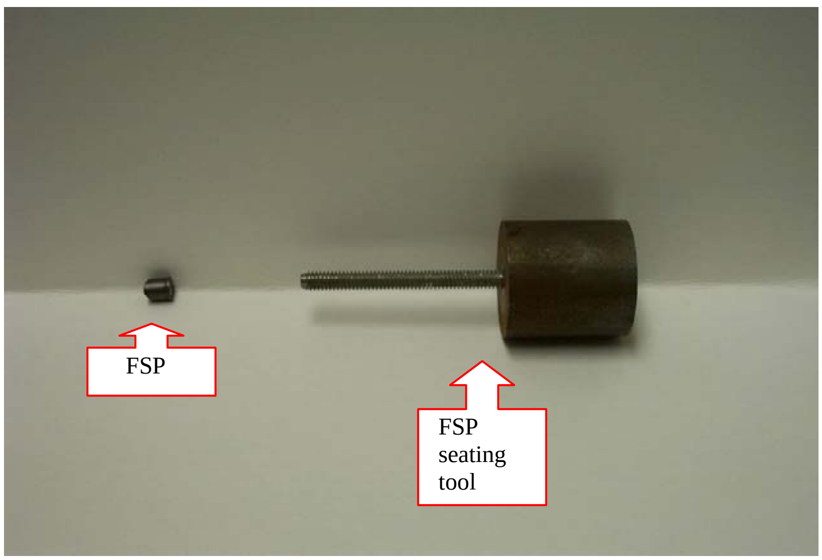


Figure 9. FSP seating tool.

7. Case Loading

Numerous measures were taken when loading propellant into the cases to keep variation to a minimum and to keep the velocities as predictable as possible. Brand new, unprimed cases were always used for each test. This insured that the case was seated all the way to the shoulder, which kept the volume between the charge and the FSP constant. Fired cases swell and do not always seat properly. Several baseline tests were performed with each barrel to develop individual powder curves (figures 10 and 11). These velocity curves were used to calculate the powder weight required to get like velocities from each barrel. A precision digital scale was

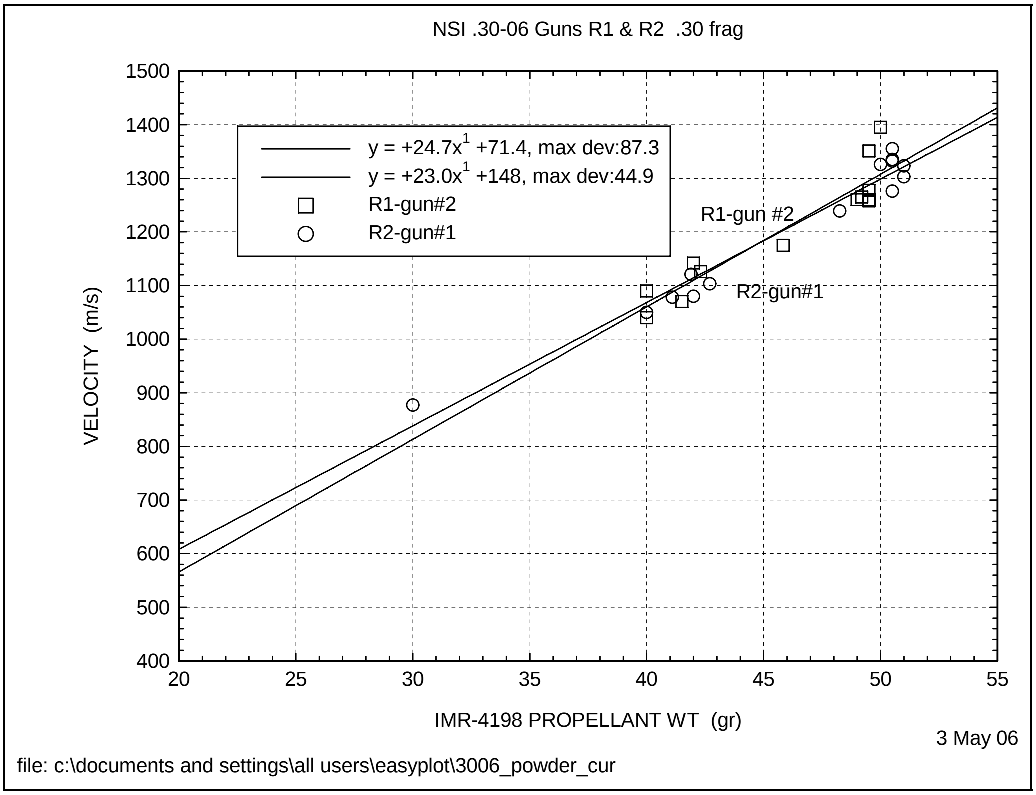


Figure 10. Gun curve for 0.3 FSP.

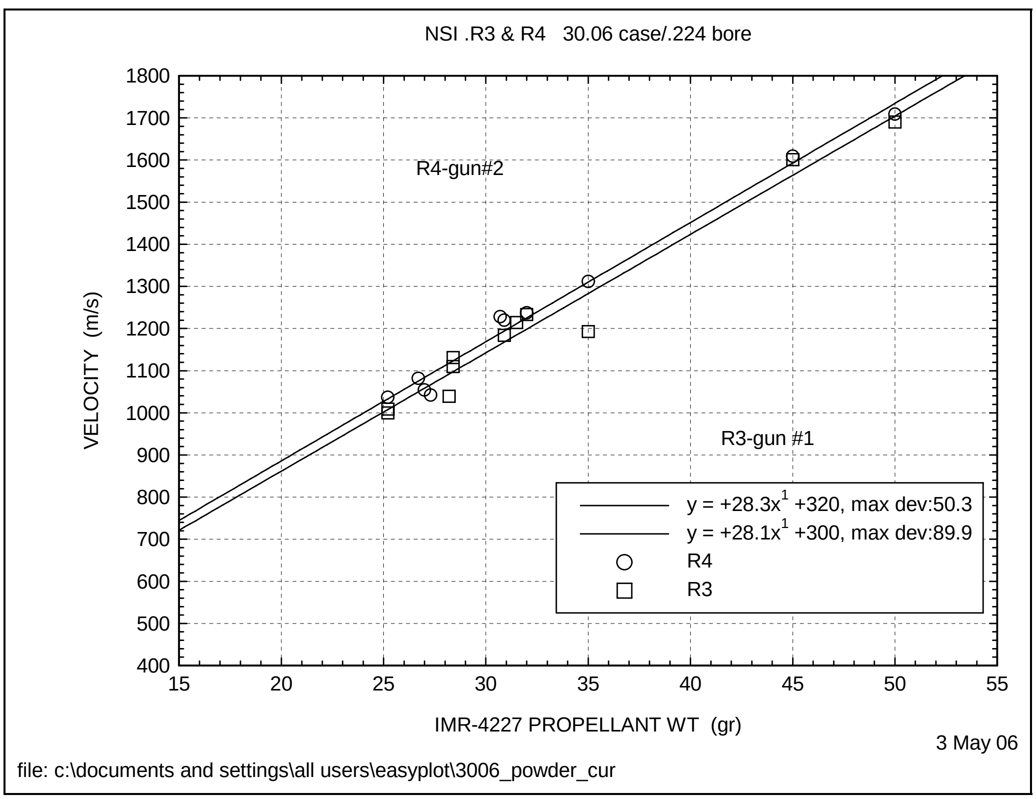


Figure 11. Gun curve for 0.22 FSP.

used to weigh our charges out to 1/100 gr, rather than the standard balance beam scale with accuracy to 1/10 gr. A blasting-approved ohmmeter was also used to check the resistance in the primers to find a pair that varied by no more than 50 Ω. Care was taken to label each case with the gun number and the powder weight after loading to insure the case was loaded into the correct barrel.

8. Instrumentation

8.1 Flash X-rays

Flash x-rays were used to analyze FSP flight characteristics (pitch yaw) and velocity measurements. Since two guns were fired at nearly the same time, the x-ray setup had to be changed in order to capture both projectiles on the same piece of film. Side heads no. 1 and 2 were set to capture the projectiles from gun no. 1 when it fired. Overhead no. 1 flashed simultaneously with side no. 1 in order to provide horizontal yaw for FSP no. 1. An additional two channels of x-rays were stacked on top of side heads no. 1 and 2. These two channels (no. 3 and 4) were set to capture the projectile from gun no. 2 when it fired. Overhead no. 2 was set to flash with side no. 4, in order to provide horizontal yaw for FSP no. 2 (see figure 12).

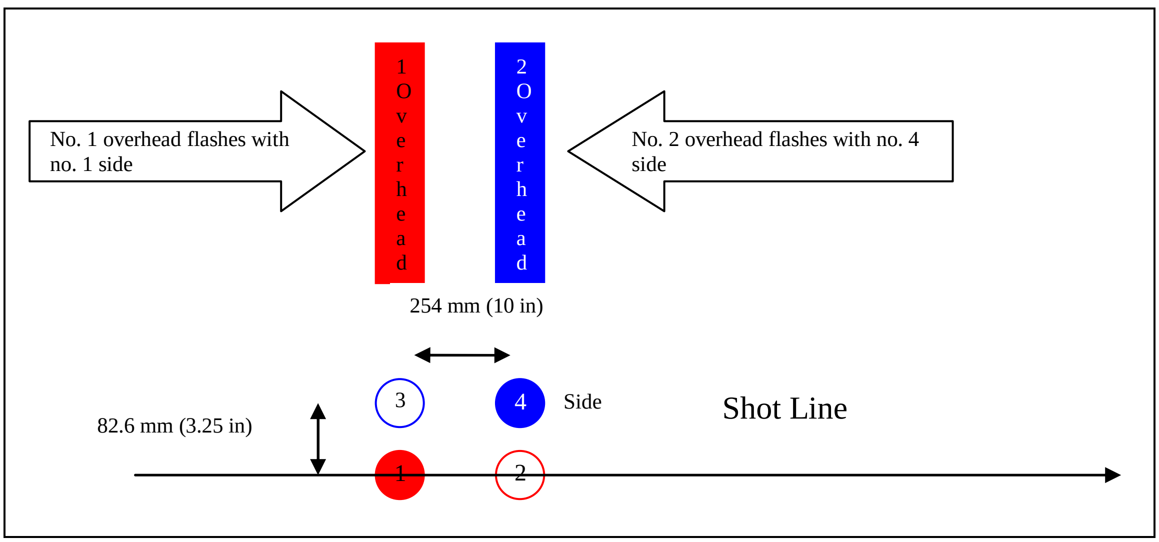


Figure 12. Side view x-ray layout.

8.2 Break Screens

The break screens that trigger the x-ray flashes for each gun had to be setup with sufficient spacing so debris from the first impact on target did not come back and break the screen for the second gun before the second projectile arrived. Early in the program, when using several hundred microsecond time delays between firing the guns, the x-ray images for the later projectile were lost because debris from the first shot broke the screen. This was solved by putting a 20-in spacing between the x-ray triggering screens. The gun that used the screen closest to the target always had a zero time delay, and the gun that used the screen furthest away from the target was the one that carried a time delay (if required) for the test. For screen placement, refer to figure 13.

Figure 13. Break screen spacing.

8.3 Make Screens

Two make-screen circuits per gun were used for these tests. The first was 0.97 m (38 in) from the muzzle of each gun (figure 14), and the second was on the surface of the target. The screens that were set just in front of the gun had to be protected from muzzle blast and possible unburnt propellant from the first gun to prevent the circuit from prematurely closing and giving a false data point. Low-density foam (0.75–1 in) was added to the front of the screen mounting panel to protect it and enable accurate make time measurement (figure 15).

These front make screens consisted of two pieces of 0.001-in aluminum foil separated by double back sticky tape mounted on a piece of 1/16-in chipboard cardboard material (figure 16). The two conductors in the make-screen circuit have a 67.5-V applied potential. When the fragment made contact and crushed the two pieces of foil together, a voltage spike was created and captured on an oscilloscope.

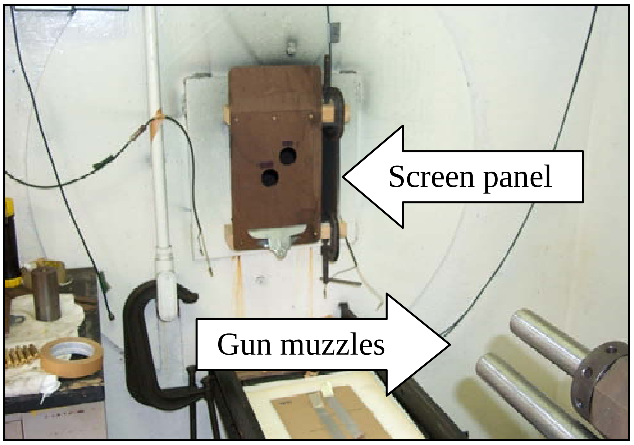


Figure 14. Front make-screen mounting panel.

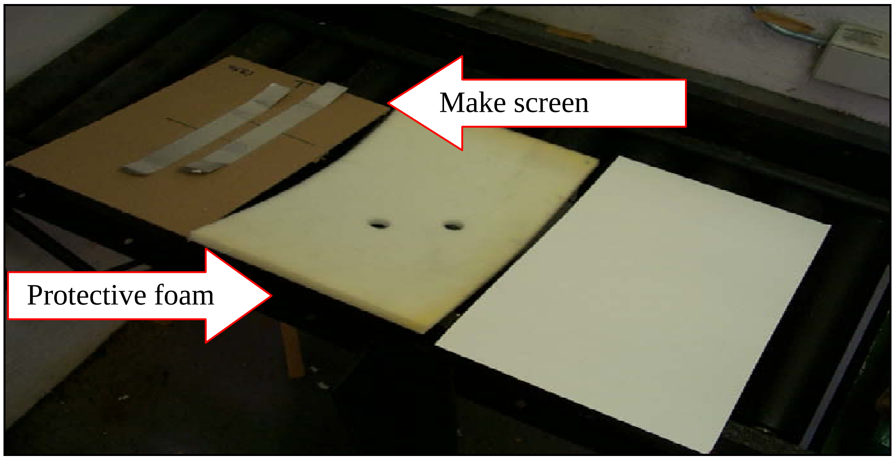


Figure 15. Front screen pieces.

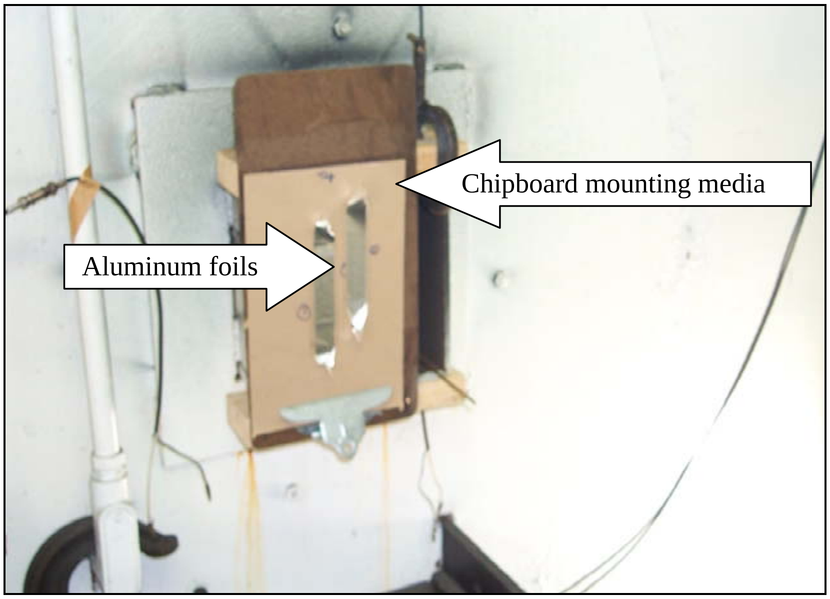


Figure 16. Front screen example.

The requirements for the make screens on the target surface depended on the construction of the target and the materials used for the front face. When the target front plate was a nonconductive material, such as a composite, a two-layer foil was applied to the surface of the target (figure 17). One layer of foil was a ground conductor, and the other layer carried a 67.5-V potential. If the front plate material was a metallic, the target stand was used as ground, and a single piece of foil was applied to the target surface to carry the voltage (figure 18). Noise buildup on the trace for the second gun impacting was one problem observed on the oscilloscope traces when using a metallic surface target (figure 19). It was theorized that this was caused by a plasma debris cloud from the first impact passing over the second impact screen circuit. To minimize this effect and clean up the base of the trace for the second impact, the surface of the target was coated with two coats of enamel paint. This insulated the screen and gave a sharper, cleaner trace on the oscilloscope (figure 20). It did not completely eliminate this noise, but it reduced it enough to allow for more accurate time measurement. Determining the time between impacts was the most important data for these tests, therefore much care was taken when preparing the target make-screen circuits.

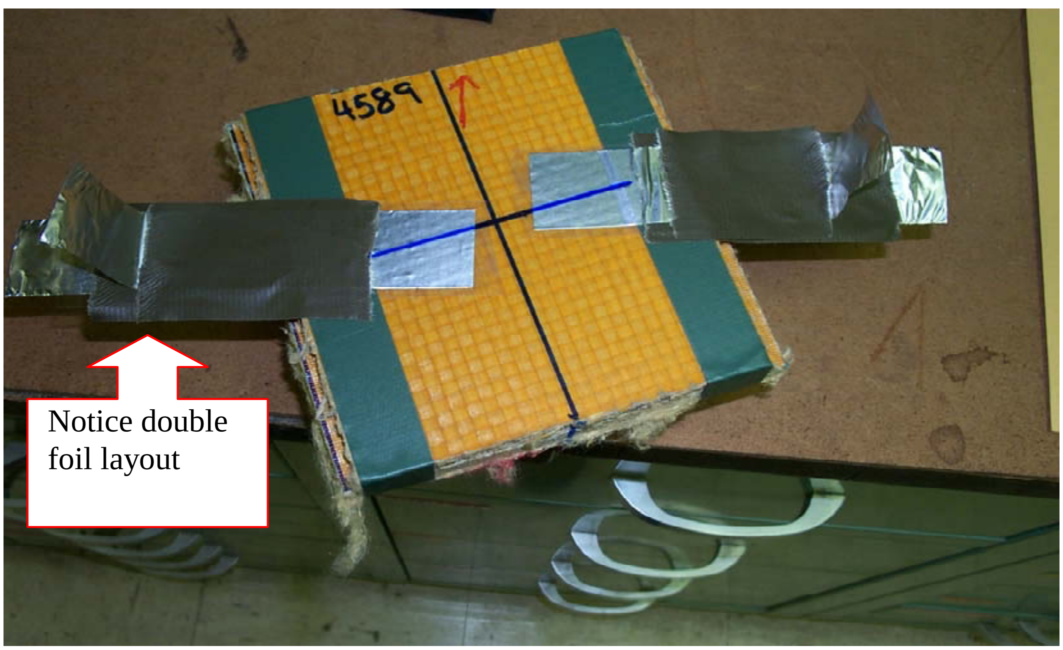


Figure 17. Nonconductive make screen.

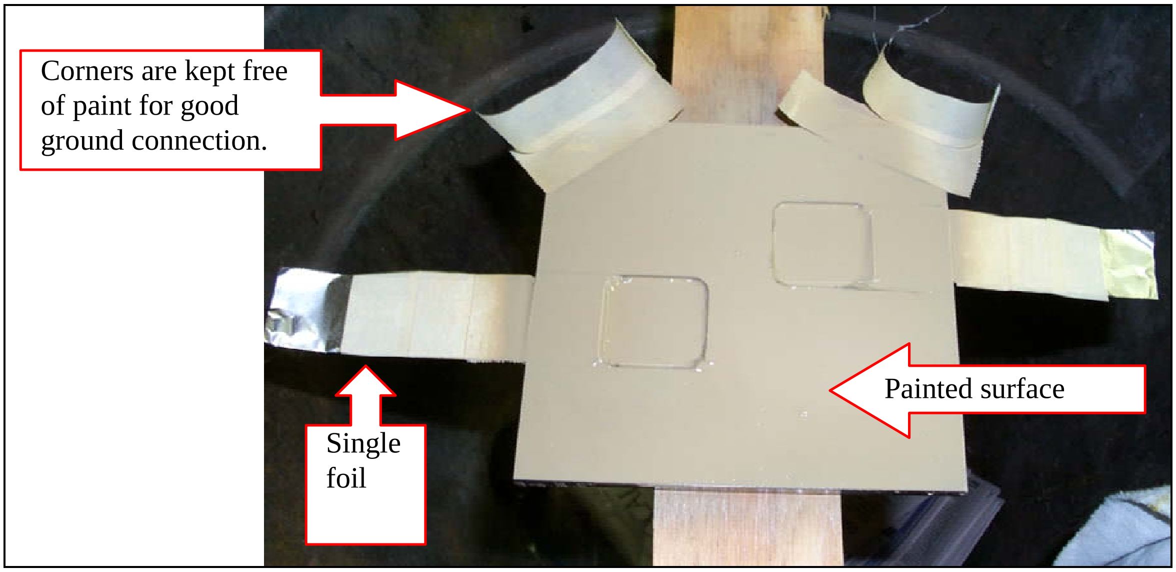


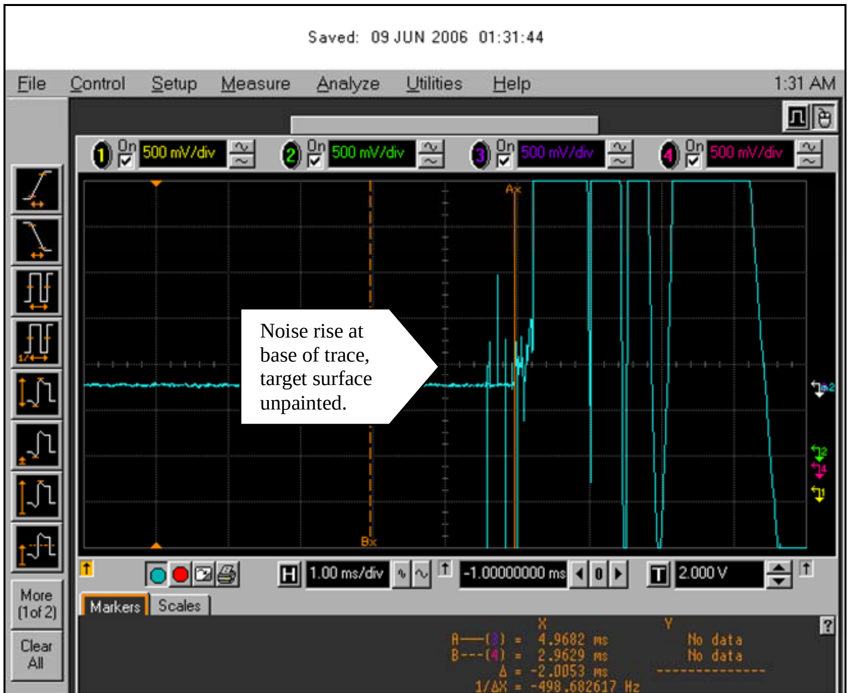
Figure 18. Conductive target surface.

8.4 Gun Firing

To initiate the guns at precise times, Berkeley Nucleonic Corporation Model 6040 Universal Pulse Generators were used. The pulse generators also had a model 202 H high-voltage module that provided output to 300 V. These units were programmable, so pulse time, pulse size, trigger size, and trigger level could be varied. The following settings were used for testing:

- Timing – single pulse, width 5 µs, delay set as required
- Trigger – external 1.2 V, trigger slope positive, single cycle
- Mode – pulse
- Level – 190 V

A pulse generator was used for each gun.

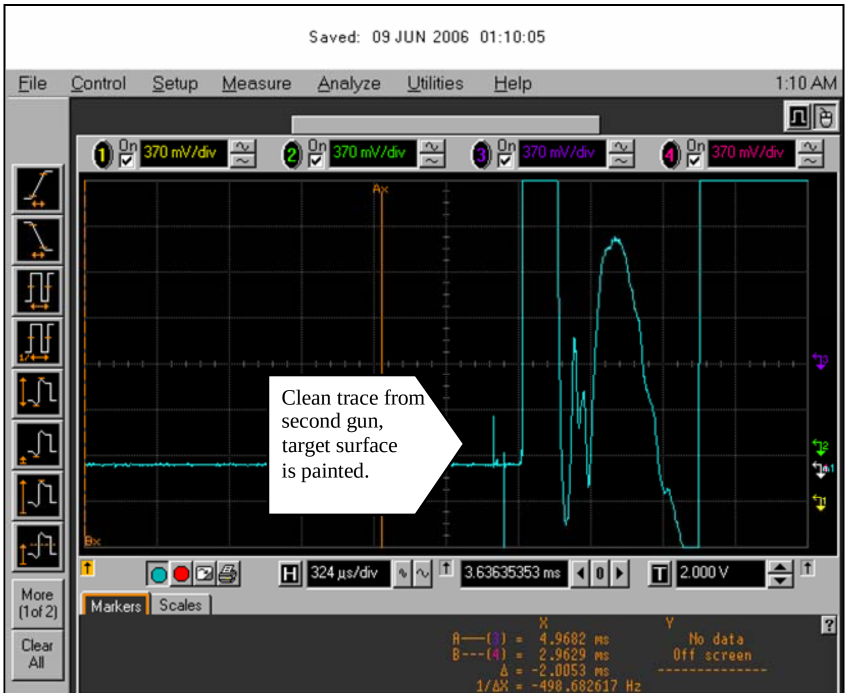


Acquisition	Sampling mode real time Memory depth automatic Memory depth 2507pts Sampling rate manual Sampling rate 250 kSa/s Averaging off 9-bit BW Filter off Interpolation off
Channel 1	Scale 500 mV/div Offset 1.359 V BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Channel 2	Scale 500 mV/div Offset 914 mV BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Channel 3	Scale 500 mV/div Offset 218 mV BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Channel 4	Scale 500 mV/div Offset 1.095 V BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Time base	Scale 1.00 ms/div Position -1.0000000 ms Reference left
Trigger	Mode edge Sweep single Hysteresis normal Holdoff time 60 ns Source aux Level 2.000 V Slope rising
Memory 2	Vertical scale 500.0 mV/div Offset 218.0000 mV Horizontal scale 1.000 ms/div Position 4.0000000 ms

Marker

	X	Y
A—(3) =	4.9682 ms	No data
B---(4) =	2.9629 ms	No data
Δ =	-2.0053 ms	--------------
1/ΔX =	-498.682617 Hz	

Figure 19. Second gun trace without painted target surface.



Acquisition	Sampling mode real time Memory depth automatic Memory depth 814pts Sampling rate manual Sampling rate 250 kSa/s Averaging off 9-bit BW Filter off Interpolation off
Channel 1	Scale 370 mV/div Offset 1.080 V BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Channel 2	Scale 370 mV/div Offset 635 mV BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Channel 3	Scale 370 mV/div Offset -61 mV BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Channel 4	Scale 370 mV/div Offset 816 mV BW limit off Coupling DC Impedance 1M Ohm Attenuation 1.000 : 1 Atten units ratio Skew 0.0 s Ext adapter None Ext coupler None Ext gain 1.00E+00 Ext offset 0.0E+00
Time base	Scale 324 µs/div Position 3.6363535 ms Reference left
Trigger	Mode edge Sweep single Hysteresis normal Holdoff time 60 ns Source aux Level 2.000 V Slope rising
Memory 1	Vertical scale 500.0 mV/div Offset 1.0950000 V Horizontal scale 1.000 ms/div Position 4.0000000 ms
Marker	X Y A—(3) = 4.9682 ms No data B---(4) = 2.9629 ms Off screen Δ = -2.0053 ms 1/ΔX = -498.682617 Hz

Figure 20. Second gun impact trace with target surface sealed with primer.

8.5 Time Measurements

Agilent oscilloscopes (model 54825N) were used to measure the time and record all the data acquired. Two scopes were used with the following input channels:

1. Scope 1
    - Channel 1 – gun no. 1 fire pulse
    - Channel 2 – gun no. 2 fire pulse
    - Channel 3 – target make circuit for gun no. 1
    - Channel 4 – target make circuit for gun no. 2
2. Scope 2
    - Channel 1 – make circuit gun no. 1, in gun room (near muzzle)
    - Channel 2 – make circuit gun no. 2, in gun room (near muzzle)
    - Channel 3 – break screen gun no. 1 (for x-rays)
    - Channel 4 – break screen gun no. 2 (for x-rays)

Both scopes were set to trigger on the auxiliary channel. A hand-held 70-V DC pulse generator simultaneously started the scopes and the pulse generators for firing the guns.

8.6 Video

A Phantom high-speed video system was used to record each test (figure 21). The camera was set up just up range from the striking x-ray area and was enclosed in protective housing. The system was trained on the front surface of the target to monitor impact time spacing and front plate characteristics during the impact. Fixed high-intensity lighting was required for video. Figure 22 shows an image of two FSPs arriving on target with an 8-μs delay.

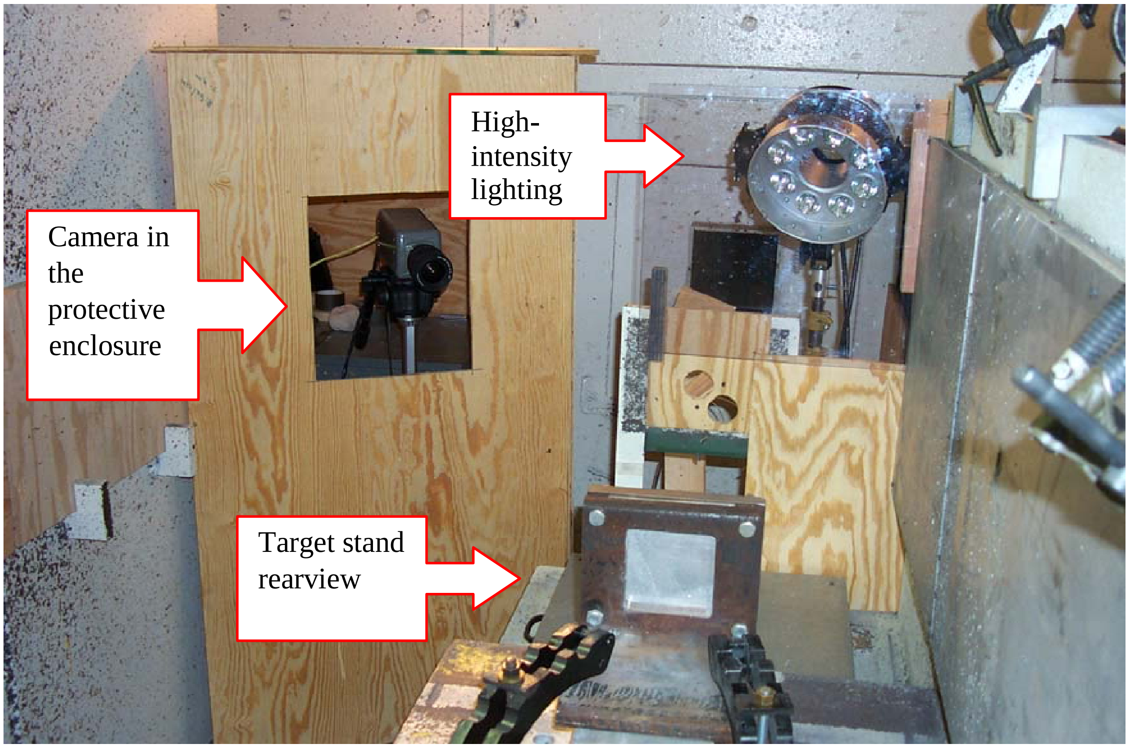


Figure 21. Phantom camera setup.

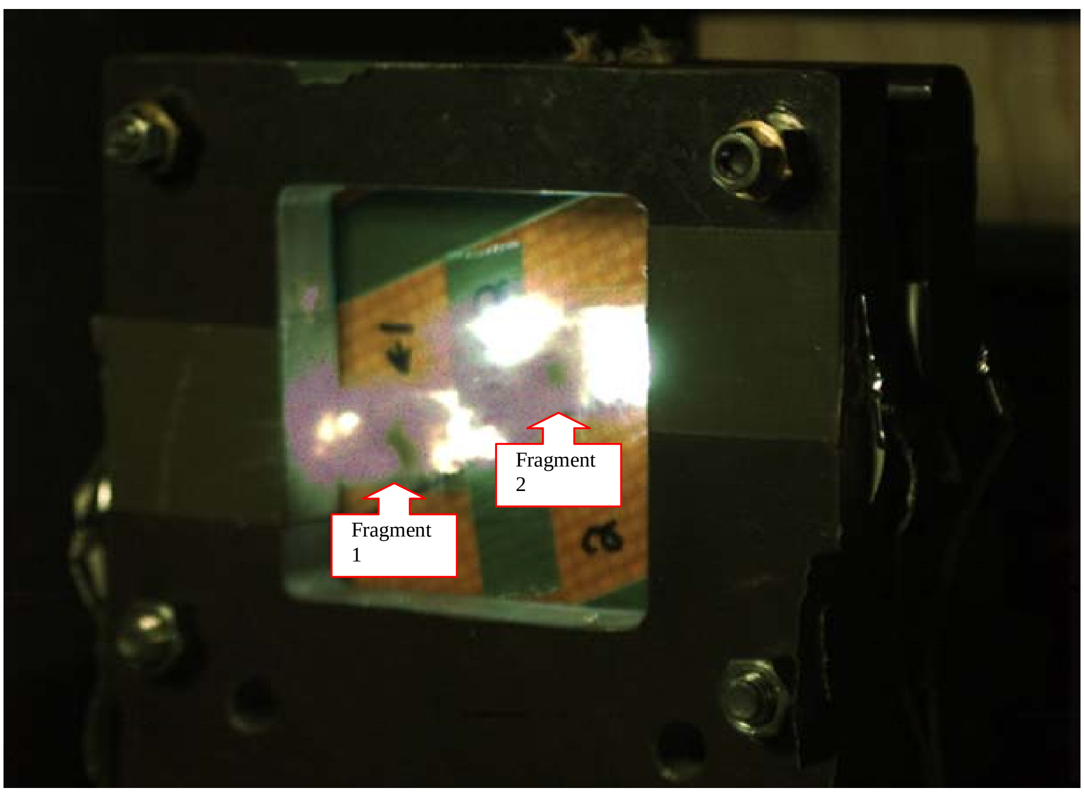


Figure 22. Two FSPs arriving on the surface of the target with 8-µs separation.

9. Conclusion

These procedures were used to successfully test FSPs in 0.22- and 0.3-caliber sizes. In order to get the fragments on the target surface at the required times, the velocity had to be very close to the expected velocity. These techniques will be applied to future tests with larger 0.5-caliber and 20-mm gun systems.

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1	SIMULA INC V KELSEY 10016 S 51ST ST PHOENIX AZ 85044
6	BAE SYSTEMS J DORSCH B KARIYA M MIDDIONE R MUSANTE R RAJAGOPAL D SCHADE PO BOX 367 SANTA CLARA CA 95103
3	BAE SYSTEMS E BRADY R JENKINS J JOHNSON PO BOX 15512 YORK PA 17405-1512

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
1	DIR USA EBCC 5183 BLACKHAWK RD APG EA MD 21010-5424
1	CDR USA SBCCOM 5183 BLACKHAWK RD APG EA MD 21010-5424
2	CDR USATEC E SANDERSON BLDG 400
2	CDR US ARMY DTC N HARRINGTON M SIMON RYAN BLDG

NO. OF COPIES	ORGANIZATION

60	DIR USARL
	AMSRD ARL WM
	  J SMITH
	  T WRIGHT
	AMSRD ARL WM B
	  T ROSENBERGER
	AMSRD ARL WM BA
	  D LYON
	AMSRD ARL WM BC
	  J NEWILL
	  P PLOSTINS
	AMSRL WM M
	  M MAHER
	AMSRL WM MC
	  E RIGAS
	AMSRL WM MD
	  E CHIN
	  J MONTGOMERY
	  K DOHERTY
	AMSRD ARL WM TA
	  M BURKINS (5 CPS)
	  W GOOCH
	  T HAVEL
	  C HOPPEL
	  E HORWATH
	  T JONES
	  M KEELE
	  D KLEPONIS
	  D LITTLE (10 CPS)
	  J RUNYEON
	  D RUSIN
	  S SCHOENFELD
	  K STOFFEL
	AMSRL WM TB
	  R BANTON
	  P BAKER
	  A GUPTA
	AMSRD ARL WM TC
	  R COATES
	  T FARRAND
	  K KIMSEY
	  T EHLERS
	  L MAGNESS
	  B PETERSON
	  D SCHEFFLER
	  R SUMMERS
	  W WALTERS
	AMSRL ARL WM TD
	  T BJERKE
	  D DANDEKAR
	  H MEYER
	  M RAFTENBERG

NO. OF COPIES	ORGANIZATION

	E RAPACKI
	M SCHEIDLER
	S SEGLETES
	T WEERASOORIYA
	AMSRD ARL SL BE
	  W MERMAGEN
	AMSRD ARL SL BD
	  R GROTE
	  R KINSLER